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NorNed – Innovative Use of Proven Technology

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SUMMARY

NorNed, the 580 km long high voltage direct current (HVDC) interconnection between Norway and the Netherlands, was put into commercial operation on 6 May 2008 after several years of planning and three years of intensive detailed engineering and construction work.

This 700 MW HVDC link utilizes a simplified bipole system with two fully insulated cable cores rated ±450 kV. The resulting 900 kV effective operational voltage leads to extra low transmission losses.

KEYWORDS

HVDC transmission
Simplified bipole
Two-core cable
Indoor converter station
World’s longest power cable

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Introduction

NorNed, the 580 km long high voltage direct current (HVDC) interconnection between Norway and the Netherlands, was put into commercial operation on 6 May 2008 after several years of planning and three years of intensive detailed engineering and construction work.

The use of the available transmission capacity has up to now been organised by a daily explicit auction. The direct income to the owners Statnett and TenneT has up to mid February 2009 (approx. first 9 months of operation) been 150 MEUR, which is about one third of the total cost of the link (excluding coupling to AC, and some miscellaneous costs like construction interest).

The plan is to present the NorNed project on a broader basis at the CIGRE general meeting in 2010. This report will focus on the conceptual background for the innovative NorNed solutions and on the main learning points, which might be important for planning of other similar projects.

Transmission scheme

When the feasibility of NorNed was positively concluded in 1992, the cost was based on a monopole scheme with sea electrodes. The capacity was therefore set to 600 MW, which at that time was considered to be a realistic rating for one cable. The concept was also built on the positive experience with Skagerrak, Fennoscan, Baltic and Kontek HVDC links. All four links are still being operated with sea electrodes with very limited complaints.

The first pre-engineering process was completed for the monopole concept and licensing notices transmitted accordingly to the Netherlands, Germany, Denmark and Norway.

The pre-engineering work included an extensive modelling of the influence from the electrodes on the electrical field distribution. The basis for sending notices was the conclusion that the area of influence after all was limited and that any problems in the influenced area could be mitigated without prohibitive costs.

The public processes raised stronger concerns than expected related to the electrolytic process at the electrodes, to the possible unforeseen effects of the magnetic field set up by the current in the cable and also to the aspects related to the possible stray current influence on infrastructure in the area close to the electrodes.

The chlorine development at the anode is well known. Toxic by-products are formed, which can be accumulated in biotops over long periods of time.

The concerns regarding the magnetic field are hard to solve with one single cable, especially in the very shallow waters of the Netherlands and Germany.

One concern is the navigation by magnetic compasses where the maximum allowable deviation was set to 5^{o}. This is impossible to fulfil in some sections of Waddenzee where the water depth is 8-10 m only, with one single-core cable.

The other even more intricate question, which needed an elaborated answer, was (and still is) the influence from the magnetic field on all sorts of marine species.

It is a fact that many of the species in these waters navigate by means of the earth magnetic field. Hence, it is possible that their navigation could be influenced by this type of disturbing field. However, from observing the conditions around all the single-core cable schemes in Skagerrak and in the Baltic Sea, there is no sign that such disturbance has any significant influence whatsoever. This is, of course, extremely difficult to prove since monitoring of marine life at upto 550 m depth is not really feasible.

Much focus was also put on the risk for corrosive influence from the electrode stray currents on infrastructure. When the southern electrode was placed reasonably close to the converter station at Eemshaven to avoid extraordinarily long electrode cables, the area of increased earth potential stretched sufficiently far into the mainland to generate difficult questions from gas pipeline owners onshore with respect to corrosive effects. Although these can be calculated and mitigated, it leaves the cable owner with the burden of proof and therefore a cost which is hard to predict and control.

All these aspects led NorNed into a process of re-thinking its configuration.

It is easy to start thinking that you in such a situation need to isolate the current and let the return current be led back close to the other current path in order to minimise the field. But how can this be done without dramatically increasing the cost?

Creative interdiscipline co-operation released the NorNed concept. It is fair to say that NKT's flat-type two-core cable, which was used in the Kontek project in 1996 inspired the development in the direction of taking into use a "simplified bipole". The concept was for the first time used with the old Cross Channel link (1961-84). NorNed is the first project to take this transmission scheme into use with ±450 kV. Since the system utilises both a positive and a negative full voltage, the term simplified bipole seems adequate.

The clue with this concept is that the cost of stations does not increase dramatically because it is only served by one set of transformers and has the same number of thyristors, however, distributed in six thyristor columns. The principle single line diagram is shown in figure 1.

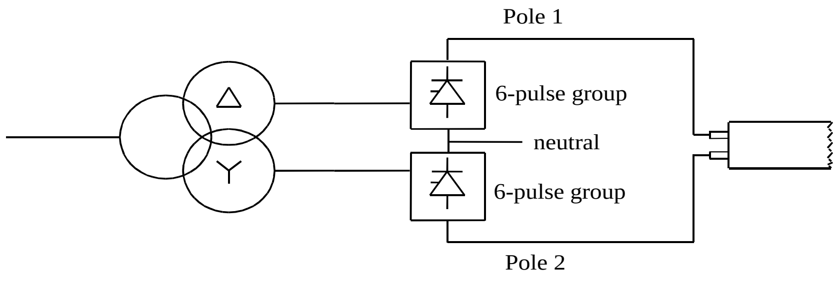

Figure 1 The simplified bipole principle

Converter stations

The converter sites are geographically dramatically different. The converter station at Eemshaven, far north in the Netherlands, is located on reclaimed land, which is completely flat and sandy, and only 2 m above main sea level. The converter station at Feda in Norway is in a narrow, mountainous valley 150 m above sea level. Both stations are only about 1.5 km from shore.

The windy, sandy and close to sea environment at Eemshaven creates relatively extreme salt and dust pollution. For that reason it was decided to make a complete indoor converter station. Even though the challenge with polluted environment obviously is more distinct on the DC side than on the AC side, also the filter was put indoors (Figure 2). The 420 kV AC connection approx. 1.5 km to the TenneT transformer station has been realised by means of 420 kV XLPE cables terminated indoors in the converter station and into SF_6 switchgear in the transformer station.

Figure 2 Eemshaven converter station

The Feda converter location is 20 km from the open ocean since the cable is first led through the Fedafjord. The narrow valley shelters the station completely from open marine environment. Therefore an outdoor DC yard and filter installation have been chosen for the Norwegian converter station (Figure 3).

Figure 3 Feda transformer

Both stations have oil-immersed smoothing reactors. This solution was chosen instead of the originally planned air-core reactor in order to improve the flexibility with respect to transmission capacity.

The need for spare converter transformers was carefully evaluated and discussed. Single-phase three winding transformers had been chosen in order to make transport easier and to potentially more easily open for spare units. It was studied whether one spare unit could serve both sides in spite of the fact that the link is coupled to 300 kV at Feda and to 420 kV at Eemshaven. It was concluded that the risk associated with complex design, construction and testing of a combined unit was too high.

This decision proved already during the construction period to be correct. If it had not been for the spare units ordered the converter stations would have been delayed due to the general overload in the transformer industry and partly caused by need for corrective actions during both manufacturing and commissioning.

Both converter station buildings were designed by architects. The thinking behind this has been part of the NorNed project's programme with respect to taking responsibility for the environment. The intention is to create a visible impression, which can be said to add value to the surroundings.

Cable

As already indicated, the cable solution for the new NorNed bipole concept was inspired by the Kontek two-core cable. The flat-type cable was even for a period considered used for the whole 580 km route.

Over time a more conservative approach was chosen, leading to use of mass-impregnated cable throughout the route. The two-core concept was, however, maintained to cope with the magnetic field limitations in the Netherlands and Germany.

The two-core mass-impregnated cable is consisting of two complete single-core cables with common armouring. It can be seen as two single-core cables bundled in the factory.

The advantage with this cable design besides the minimised magnetic field, is that it can be handled by one turntable on the cable installation ship. It also reduces the number of trenching operations and/or rockdump operations to one. It also provides advantages in terms of predictability and product safety regarding in-line jointing operations (field jointing offshore).

The disadvantage is more complicated handling of the cable during laying and potential repair operations since the two-core cable can only be bent in one direction. NorNed has, however, already proven its repairability two times during commissioning work.

The repairability aspect, however, caused use of single-core cables in the deep part of the route, which is across the Norwegian trench and in the outer part of Fedafjord (410 m). The deeper the water, the more burdensome the handling for repair operations will be. In deep waters, the magnetic field causes less concern than in the shallow waters further south.

The use of single-core cable in the relatively shallow water mid-way up to the Norwegian trench was mainly motivated by a more rapid start of cable manufacturing in 2005, thereby securing the presumed short construction period. An overview of the complete cable system is shown in figure 4.

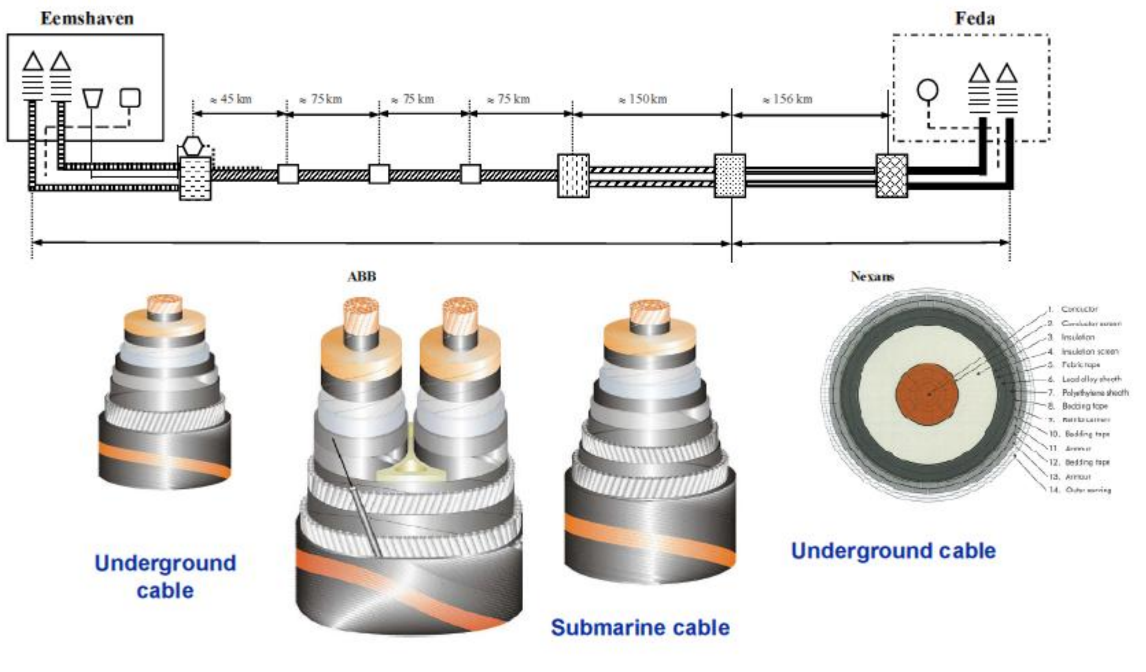

Figure 4

The manufacturing of the 45000 tons of cable represents a tremendous challenge with respect to quality and timely delivery. The latter came through without many remarks.

With respect to quality it is also reason to be satisfied, however, with some remarks.

Both manufacturers to NorNed turned out to be dependent on a certain number of repairs in order to cope with mishaps in their factories. It is important to establish a system for inspections and handling of non-conformities in order to maintain full product quality. It is also important to arrange sufficient float in the scheduling to allow for delays caused by repair of non-conformities.

The other remark is that the delivery acceptance testing recommended by CIGRE [1] does not seem to be fully adequate. In at least one of the incidents experienced in NorNed leading to repair before the link could be put into operation, the cable damage (or part damage) must have been present in the cable before installation. This was neither discovered during the high voltage test after load-out nor during the after installation test. It is recommended that more research is considered with respect to improved test methods for mass-impregnated HVDC cables.

The NorNed offshore installation challenge also turned out to be more challenging than expected. The route length is close to 576 km subsea and 4 km onshore (cable length to be installed 270 km + 2 x 308 km = 886 km). The North Sea is a rough arena, partly open to the Atlantic and to the Norwegian Sea, where wind and swell build up rapidly. Because of the exposure to the huge open seas the swell can last for a long period after the wind disappeared. The swell is probably the largest problem when installing cable.

This is particularly challenging for the offshore field jointing when the cable must be riding on the laying wheel for a long period (4-6 days) with very limited possibility to change cable position. It can easily be observed that the type testing recommended by CIGRE [1] does not cover this type of strain.

When this aspect was carefully evaluated in the NorNed project as part of pre-engineering, the consideration was (and still is) that this type of strain is by experience a type of strain, which this product can and will withstand. The main argument for this is the nine cable repairs Statnett has experienced with the three Skagerrak cables, first incident being as early as in 1976. These in total 18 repair joints have all survived till now, some of them even experiencing a storm during the jointing process. However, in NorNed where responsibility for cable delivery and installation were separated, lack of formal qualification of the product led to unresolved liability discussions. Therefore it should perhaps be considered whether a testing of limits with respect to handling during different types of field work should be developed.

After all, laying, jointing, repairing, trenching and rock dumping of 886 km across the rough North Sea went without fatal accidents and with few incidents. The result is that the 886 km of cable are very well installed with consistent and good protection against all known fishing gear and anchor chains. The hope is that the maintenance workthrough the cable lifetime shall be limited to inspections and to a few re-trenching or rock dump operations.

Discussion

When trying to contemplate what can be learnt from the execution of the NorNed project, the following aspects are considered to be worth mentioning:

Technological aspects

The main learning points with respect to technological solutions have already been explained. However, when summarising it should be underlined that the high transmission voltage of NorNed, 900 kV, is creating a very efficient transmission system with very low transmission losses 4.2 % at 700 MW (receiving end). The solution could probably be used up to 1000 MW and should be studied as an alternative to a full bipole solution.

Already during the construction period NorNed experienced the importance of investing in spare transformers. Due to the long lead times for manufacturing of new units, it will be beneficial in the long run to secure sufficient spare parts for the total system, both for cable and converters.

The operational experience during the first nine months has been reasonably good, but not without unscheduled outages. NorNed experienced a cable failure right outside the converter station in Eemshaven on 9 February 2009. This cable failure led to approximately 14 days of outage (4 % of a year). At the moment, the failure cause has not yet been clarified.

NorNed has also experienced outages of much shorter duration (max. one day) caused by malfunctioning of the control system or of the interface between the control system and the SCADA systems. This problem is still being investigated.

Contract structure

NorNed has been successfully implemented based on seven major independent contracts (one converter contract, one civil construction contract in the Netherlands, two in Norway, two cable supply contracts and one cable installation contract). TenneT and Statnett have taken the resulting interface risk. The contractors have been co-insured under TenneT's and Statnett's construction all risk insurance specially arranged for NorNed. With the experienced mishaps and challenges it is quite obvious that a contract arrangement more towards a turnkey structure would easily have created more delay caused by risk aversion.

The split in two cable contracts was mainly caused by the maximum 3 year implementation requirement (cashflow). This has added to the interface complexity to a degree which preferably should have been avoided. It has, however, been fully manageable.

It is also quite obvious that the NorNed contract structure has been cost efficient. The 495 MEUR for 700 MW and 580 km cable route length and 4.2 % transmission loss will be hard to beat.

Organisation

The extraordinarily long planning period of NorNed from 1994 to 2004 was partly caused by contractual unbalance between the Dutch and Norwegian parties. The key to successfully start the implementation was a renewed arrangement with a 50/50 cost sharing between TenneT and Statnett. This created a ground of common interest which enabled building an organisation for the implementation, which could rationally and efficiently make decisions for the project to maintain sufficient progress in the construction work. In this context, it was also important that it was possible to secure continuity of some key resources from the planning period.

The income side

Equally important to the 50/50 cost sharing principle was the agreement between TenneT and Statnett to also share the direct income generated by the HVDC link in the same manner.

It has turned out that this win-win type arrangement has created the necessary driving force and co-operative environment for an efficient implementation of such a costly and relatively high risk project.

It is considered important also for new projects in the future that the involved parties are looking for win-win schemes and equal opportunities

BIBLIOGRAPHY

[1] Recommendation for Mechanical Tests on Submarine Cables (Electra No. 171 April 1997)